Participatory Agent-Based Modeling and Simulation of Rice Farming in the Rainfed Lowlands of Northeast Thailand

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Abstract: Rainfed lowland rice production in lower northeast Thailand is a complex and adaptive farming activity. Complexity arises from interconnections between multiple and intertwined processes, particularly agronomic practices and labor migration. Having faced a heterogeneous and very variable environment for centuries, local rice farmers are very adaptive and used to adjust their behavior in unpredictable farming conditions. Based on the principles of the Companion Modelling (ComMod) approach, indigenous and academic knowledge was integrated in an Agent-Based Model (ABM) to build a shared representation of this complex and adaptive system. The ABM was co-designed over a 3 years long process with a group of different types of rice growers from Ban Mak Mai village in southern Ubon Ratchathani province. This participatory modeling process also aimed at stimulating participants' thinking and co-learning through the collective exploration of simulated scenarios with varying levels of water and labor availability, with the ultimate goal of further strengthening their adaptive management ability.

The ABM consists of three interacting modules in a virtual rainfed lowland rice environment: Water (hydro-climatic processes), Rice, and Household. "Household" is a rule-based agent making daily decisions based on its available means of production depending on the stage of the rice crop, and water and labor availability. Key decisions made are related to: i) rice nursery establishment, ii) rice transplanting, iii) rice harvesting, and iv) migration of household members. The spatially-explicit model interface represents an archetypical toposequence made of upper to lower paddies in a mini-catchment farmed by 4 different households and includes also water bodies and human settlements. According to participating farmers, after many iterations between the lab. and the field, this ABM adequately represents their rice farming and labor migration management practices. Using the model to raise farmers' awareness of the system emergent properties as a consequence of interactions between rice farming and labor migration is also discussed.

Keywords: Agent-based modeling and simulation, Companion Modelling, rainfed rice farming, labor migration, northeast Thailand.

INTRODUCTION

85% of the 5.2 million ha of rice areas in Northeast Thailand are farmed under rainfed conditions with a single crop per year and low productivity of paddy rice averaging 1.8 t ha^{-1}. This is mainly the result of low water-holding and infertile coarse-textured soils and erratic rainfall distribution[15, 29]. Notwithstanding, 25% of the households living in this most populated region of the kingdom are still engaged in rice production[25]. But cash incomes generated from rice production are inadequate to meet their basic needs, leading to a relatively high rate of poverty in this region. Therefore, to improve their livelihoods, these resource-poor rice farmers have been involved in labor migration for a long time to access off-farm jobs in urban areas, causing labor scarcity at household and community level. More than a third of all interregional migrations still originates from this region[28]. Successive state policies have been implemented to upgrade farmers' livelihoods by mitigating agro-ecological constraints, but met with limited success. Today, in particular, a new water improvement scheme proposes to invest 15 billion US dollar in the construction of a future ambitious "hydro-shield tunnel" to divert water from the Mekong River to supply 19 provinces in the Northeastern region. As in the past, the success of water improvement schemes could be limited if they are not based on an in-depth understanding of the interactions between water use, farmers' rice production practices, and labor migration.

Rainfed lowland rice (RLR) farming in lower northeast Thailand is a very complex and adaptive system (CAS). Complexity arises from the

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interconnections between multiple and intertwined processes, particularly rice production practices and labor migration. Having faced a heterogeneous and very variable environment for centuries, local rice farmers are very adaptive and used to adjust their behavior in unpredictable farming conditions. Agent-Based Modeling and simulation is more and more widely used to represent, track, and analyze the dynamics of such CAS. Agent-Based Models (ABM) explicitly represent human decision-making processes[14] by means of agents set as autonomous computer entities interacting directly among themselves and with their common environment, in order to achieve their goals [12, 30]. An agent has some specified knowledge about the system in which it is situated and operates (but it is not omniscient). By nature, an ABM provides a representation of a real system that is less abstract than a mathematical model. Therefore, it is a promising tool to promote discussion and further exploration among researchers and model developers, but also subject matter specialists, policy-makers as well as local stakeholders [24]. The Companion Modelling (ComMod) approach has been designed for such a purpose: it is an iterative, continuous, evolving approach to facilitate dialogue, shared learning and collective decision-making through interdisciplinary and research in action processes to strengthen the adaptive management capacity of stakeholders facing a common resource management problem [5].

Past studies have examined labor migration as a result of economic drivers, such as push and pull factors in the neoclassical economic theory [7, 8, 19, 26], often at macro level. Some studies [10, 13] focused on the migration decision-making process as a result of the interaction between individual or micro-factors (often referring to demographic and social characteristics) or macro factors ranging from household to community levels (often referred to economic-related factors). But few studies have examined the relationship between renewable natural resource use and labor migration [27, 28]. And fewer of them used ABMS to assess changes in technologies and land use in relation to labor migration [17, 18]. Recent studies of RLR systems and RLR crop modeling carried out in this region took rainfall variability and the risk of drought into account. But none of them integrated the key interaction between rainfall distribution and farmers' decisions regarding RLR crop management [3, 4].

Therefore, the purpose of this research is to build a shared representation of the interactions between RLR farming, water availability, and labor migration by integrating indigenous and academic knowledge through a process of collaborative construction of an ABM with local RLR growers. We also aim at stimulating the participants’ thinking and co-learning through the collective exploration of simulated scenarios displaying varying water and labor availability, with the ultimate goal of further strengthening their adaptive management ability throughout this very interactive participatory modeling and simulation process.

First, the structure of the ABM and the main processes represented in it are described. Then, the simulated scenarios identified by the participating local farmers are introduced and the salient points of the simulation results discussed with the researchers are presented. Finally, the effects of such collaborative modeling activity on farmers’ awareness of the system emergent properties resulting from the simulated interactions between RLR farming and labor migration are discussed.

THE BanMakMai AGENT-BASED MODEL

The development of the ABM involved a heterogeneous group of RLR farmers from the Ban Mak Mai village since the beginning of the design process, hence its name: the BMM agent-based model.

A model designed with farmers

In agreement with the ComMod approach, our objective in designing and using an ABM with farmers was to support a co-learning process on the complex situation to be examined to improve farmers’ and scientists’ knowledge on its functioning by elucidating, and sharing diverse perceptions. Thus, the RLR growers’ involvement to explain their decision-making processes regarding farm management was needed to allow such exchanges and the integration of indigenous and academic knowledge.

The study area is located in the Lam Dome Yai watershed, south of Ubon Ratchathani province. It is covering 1,680 km^2 in Det Udom and the northern part of Na Chaluay districts where 80% of the land is planted to RLR[21]. Within that area, the Ban Mak Mai village was selected, as it typically represents the regional RLR-based farming system.

Within this village, 11 farming households ranging from small farms (average size of 3.2 ha), to larger holdings (average size of 7.2 ha), were recruited to take into account the diversity of farming conditions among households having different amounts of productive assets, socio-economic strategies regarding RLR production and labor employment. Husband and wife of each selected household were invited to participate in each of the successive modeling field workshops held in this village.

A 3 years long iterative collaborative modeling process

In this experiment, 6 successive participatory workshops were held in the village to co-design the ABM with the different types of rice growers. In the early stages of the process, participants were requested to make decisions under circumstances very similar to their actual ones (farm size, pond size, location of farm, family labor and members, etc.) and the participants played their own roles in role-playing games (RPGs) [22]. During the first 3 workshops, this particular type of participatory simulations was used to facilitate interactive knowledge sharing between participating farmers and researchers, and to acquire new information emerging from players' interactions when facing different situations regarding water availability. On the way from the RPG to the ABM, a couple of additional participatory workshops using prototype versions of the ABM derived from the previous RPGs were organized to agree on the formalization of the main decision-making processes regulating the relationships between water dynamics and farm management including labor migration (Figure 1).

Model description

The BMM model is a spatially-explicit agent-based model made of three interacting modules i.e. a water module (to account for hydro-climatic processes), a RLR module, and a household module (Figure 2). The BMM model is run with a daily time step. The initial date is set on 1st of April, at the end of the dry season. In every step, each simulated household has to make rice production and/or labor management decisions. The BMM model is designed to allow up to 10 years long simulations.

Spatial settings

The BMM model spatial configuration is based on field, farm, and community levels representing three land use types: upper to lower paddy fields, water bodies such as farm ponds and stream, and human settlements such as houses, village, and city (Figure 3). The smallest spatial unit, or cell, is equal to 0.04 ha (1 *ngan*, a Thai area unit). Elevation ranges from 97 to 133 meters to represent a regular slope from lower (close to the stream) to upper paddies (close to roads). The properties of the sandy Korat soil series found in this area are applied to each cell [2]. A paddy field is an aggregation of cells, and a farm is an aggregation of paddy fields. To represent the heterogeneity of farm size and water availability, two small farms (3.3 ha) and two large farms (6.5 ha) with different farm pond size were implemented.

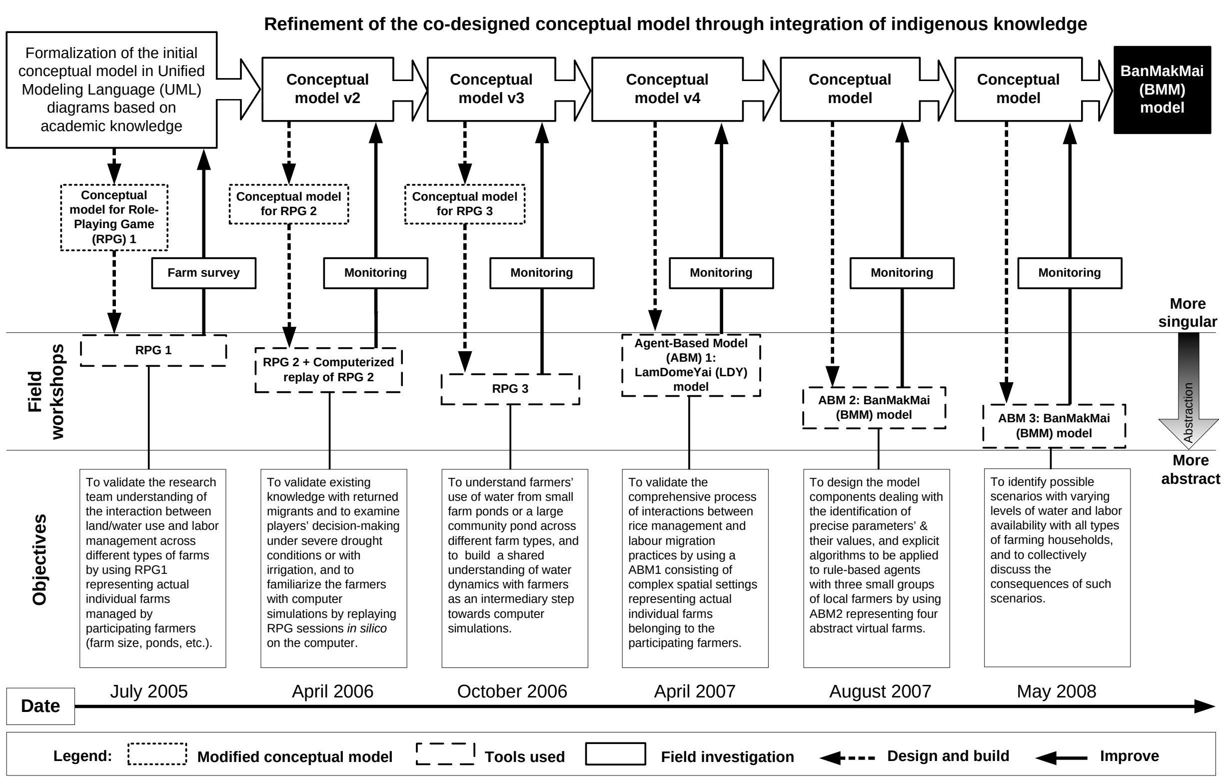

Figure 1. ComMod process conducted with 22 rice farmers in Ban Mak Mai village, Det Udom district, Ubon Ratchathani province showing objectives and tools used of 6 participatory workshops.

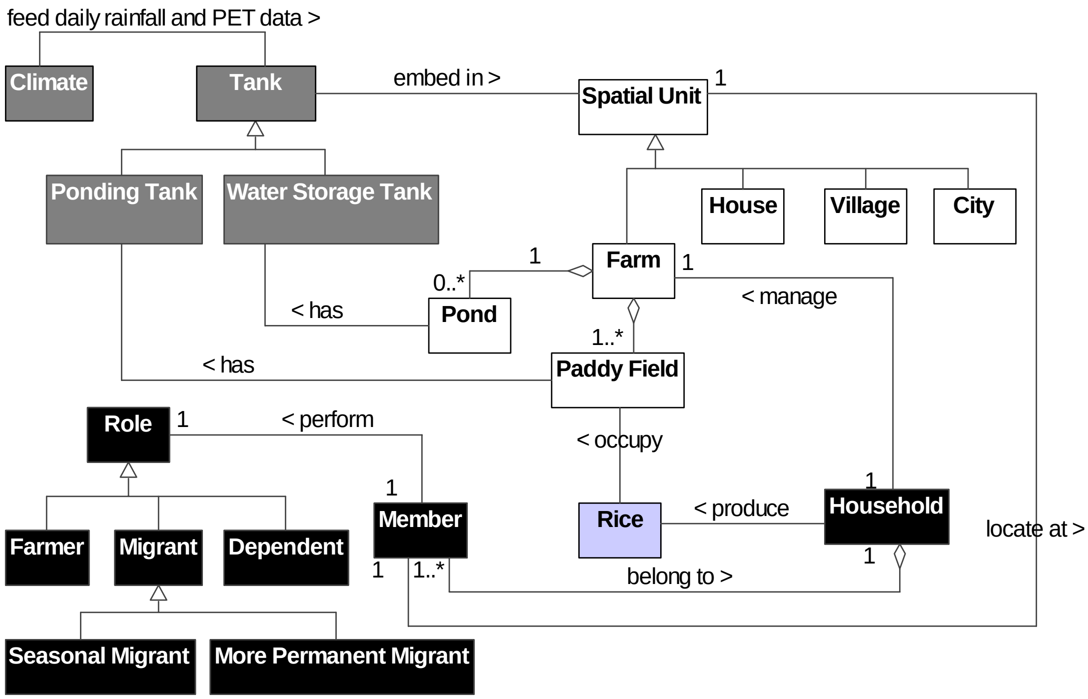

Figure 2. The BMM conceptual model in a UML class diagram representing key entities and their relationships.

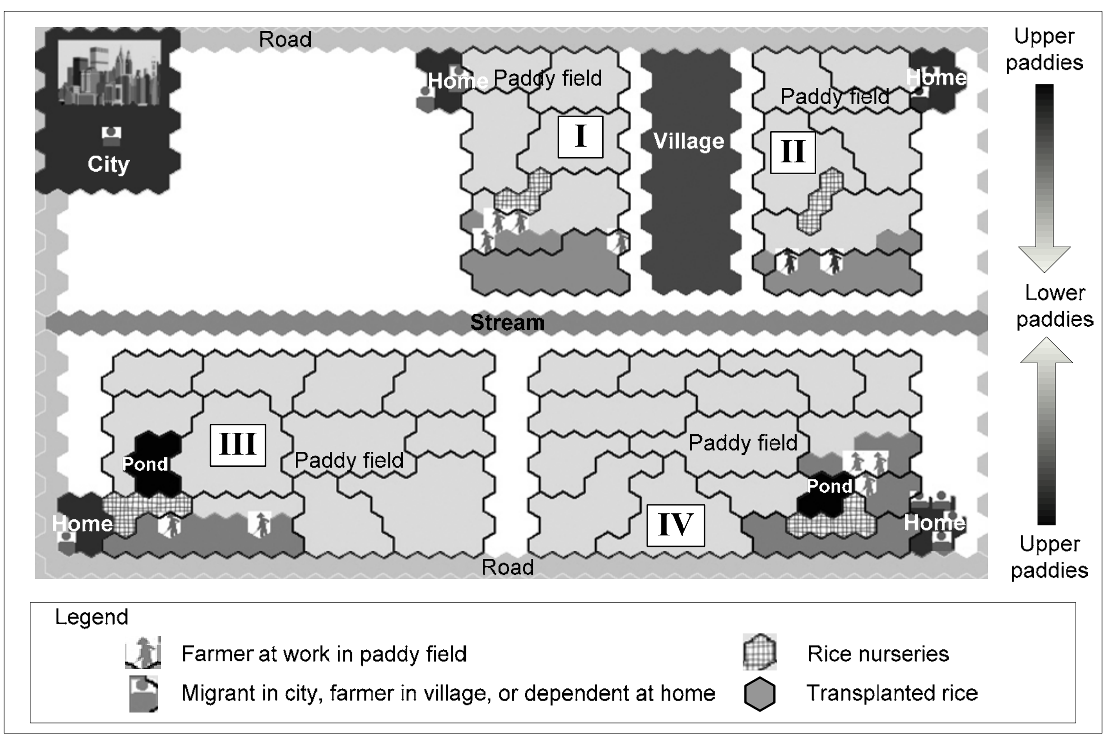

Figure 3. Spatial configuration of the BMM model representing two small farms (I and II) and two large farms (III and IV) during rice transplanting.

Water module

Water is entering the system via the input of daily rainfall data. A predefined set of daily precipitations over 10 years (duration of a simulation run) obtained from the Ubon Ratchathani regional meteorological center is used in the simulation runs. Two types of hydrological tanks are defined: a ponding tank for each paddy field, while a single water storage tank is associated to each farm pond. In addition to the direct input of rainfall in each tank, overflowing tanks are filling lower neighboring paddies through runoff. Finally, a constant (10 mm) quantity of water is deducted each day from each ponding tank to account for the overall functioning of the soil-plant system.

Rice module

This module provides information to Households about the RLR growth stage at any given time. Two, early and late maturing, photo-sensitive rice varieties are used in the BMM model as these two types of cultivars are combined on the local farms. They have different parameters affecting the decision to harvest: the early maturing rice variety is ready for harvest on November 10, while the late maturing one is ripe on November 21. Information from this module prompts Households to act accordingly. However, climatic conditions (dry spells early in the season, or rainy days during harvest affecting paddy quality) also determine whether such actions are possible or not.

Household module

This module integrates three aggregated social levels: individual, household, and village. Each individual household member is holding one out of three possible roles i.e. Farmer, Migrant, or Dependent depending on his/her activity at a given time (Figure 2). The location of an individual member on the spatial grid indicates his/her role (Figure 3): Migrants are in the city; Farming members are located in paddy fields (when growing RLR) or in the village (when waiting for employment on other farms). The four households represented were created with different size, assets and number of workers. Smallholdings I and II have six members with household I having three laborers and three dependents while household II has four laborers and two dependents. Larger farming units III and IV have two laborers and one dependent, and three laborers and four dependents respectively (Figure 3).

Sequence of farming activities throughout a crop year

The Household agent controls the activation of a sequence of farming activities, updated on a daily basis, as the result of the interactions between the availability of water and the successive RLR growth stages. The key successive farming activities are as follows: establishment of RLR nurseries and production of seedlings, transplanting, and harvesting. After RLR harvest, each household computes the results of the rice season and decisions about labor migration are individually considered by each member.

Nursery establishment and production of seedlings

Following the 2nd week of May and the Royal Plowing Ceremony in Bangkok, Households consider the possibility to establish rice nurseries. Without a pond or without sufficient water volume in the pond (less than 10% of pond capacity), the decision to establish a nursery relies only on rainfall (see corresponding threshold in table 1). Once the nursery is established, a water stress occurs if there are 12 successive days without rainfall higher than 10 mm/day. Under such circumstances, if the household has a pond with enough water, it is pumped to alleviate the water stress, otherwise the nursery is partly (1/3) destroyed and the household has to re-establish another one to produce this quantity of seedlings. At the age of 30 days, RLR seedlings are ready for transplanting.

Transplanting

All Households wait for a daily rainfall higher than 20 mm to start transplanting and all seasonal migrants return home at that time. Early-maturing rice is first transplanted in the upper paddies, then late-maturing rice starting from the lowest paddies. When a Household sees that it cannot complete transplanting with family labor by September 15 (after that date the duration of the RLR vegetative phase would be too short to achieve satisfactory yields), additional labor is hired. Farm ponds are not used for this activity implemented during a usually very wet period.

Harvesting

RLR varieties are photo-sensitive and are ripe one month after flowering. Therefore, all households start to harvest rice at the same time. Once harvesting has started, if the daily rainfall is over 30 mm (wet day threshold), this activity will be paused and resumed one day later. The labor availability is critical for the production of quality late-maturing rice variety for sale, as a fast harvest yields a higher paddy quality sold at a higher farm gate price (Table 1). Therefore, hiring labor is considered necessary for all farms to accelerate harvesting, so that it can be completed before December 1. When harvesting is under way, all farms have the same objective of getting high quality paddy but if it not possible (as December 1 already passed), then to get fair quality paddy. If it is not possible (after

December 10), there is no more reason to rush to finish harvesting RLR and therefore no labor is hired.

Relations between RLR production and decisions on labor migration

Once RLR production activities are completed, late-maturing rice sales, local off-farm incomes (wages received when transplanting and harvesting on other farms) and labor costs (wages paid to hired labor) are calculated for each household. Afterwards, the demographic characteristics of their members, which are important to determine potential migrants and migration patterns, are updated. Two kinds of migration are taken into account. Seasonal migrants always return home to help in RLR production at transplanting and harvest, while more-permanent migrants are removed from the list of family farm laborers. The criteria to become a potential migrant, and selection of migration patterns are based on the Value-Expectancy model (De Jong 1997) [10].

First, a member evaluates its migration intention (none, low, or high) based on its personal characteristics (age, gender, marital status, migration experience). The member also considers its Household’s socioeconomic conditions (presence of dependents, financial situation after rice sales and wage earned as hired labor, subtracted by farm input and labor cost). After combining these two dimensions, the member finally makes his/her decision whether to migrate to the city in the dry season (seasonal migrant), to work in urban areas without returning home to help on the farm (more-permanent migrant), or stay at home.

COLLECTIVE DEFINITION AND EXPLORATION OF SIMULATED SCENARIOS

The spatial settings and characteristics of the four households and their members presented in the previous section were used to define a baseline scenario. We used it to calibrate the model and as a reference for comparisons with other scenarios. Two of them emerged from the discussions with participating farmers held in May 2008. The first one includes the availability of cheap foreign laborers from the Lao PDR and Cambodia during transplanting and harvest. The second proposed scenario assumed that enough water is accessible to all farms (for instance through an irrigation canal).

Cheap foreign labor scenario

The simulation of this scenario, based on the availability of 30 hired laborers from neighboring countries ready to work at low wages, showed a high income differentials across farm types compared to the

Table 1.Default values, units and sources of key parameters for each module of the BMM model.

Module	Parameter	Default value	Unit	Source & main tool used
Water	Water quantity needed to supply a 0.04 ha RLR nursery	40	m^3	Field workshop based on RPG3
	Minimum depth of water level needed in farm ponds	10	%	Field workshop based on RPG1
	Daily volume of water (related to soil-plant system) deducted from a ponding tank	10	mm	ABM calibration
	Daily rainfall threshold to initiate RLR nursery establishment	30	mm	Field workshop based on RPG3
	Daily rainfall threshold to start transplanting	20	mm	
	Daily rainfall threshold to stop harvest for one day	10	mm	
Rice	Minimum daily rainfall of a wet day at nursery stage	10	mm	Field workshop based on ABM2
	Duration of dry spell for water stress to occur in RLR nurseries	12	day	Field workshop based on ABM1
	Maximum RLR paddy yield	2,250	kg/ha	Field workshop based on RPG1
	Minimum RLR paddy yield	938	kg/ha	
	Age of RLR seedlings ready for transplanting	30	day	
	Duration of transplanting after rice seedlings reach 30 days	21	day	Field workshop based on ABM2
	Last week to establish RLR nurseries	3^{rd} week of July	week	Field workshop based on RPG1
	Last week for RLR transplanting	2^{nd} week of September	week	
	Starting date of early maturing rice harvest	10^{th} November	day	Bureau of Rice Research and Development, 1999
	Starting date of late maturing rice harvest	21^{st} November	day	
	Maximum harvesting date to get high quality paddy	1^{st} December	day	Field workshop based on ABM2
	Maximum harvesting date to get fair quality paddy	10^{th} December	day	
	Farmgate price of high quality paddy	18	baht/kg	Thai Rice Mills Association, 2008
	Farmgate price of fair quality paddy	12	baht/kg	
	Farmgate price of low quality paddy	9	baht/kg	
Household	Beginning of RLR nursery establishment	2^{nd} week of May	week	Field workshop based on RPG1
	Maximum age of migrant villagers	45	years	Field workshop based on ABM2
	Average annual net income per household	20,000	baht	NSO, 2007
	Average farm input cost excluding labour cost	3,750	baht/ha	OAE, 2005
	Volume of paddy for self-consumption	350	kg/person/year	Authors' farm survey in 2004
	Rate of daily wage at RLR transplanting	120	baht/person	Field workshop based on ABM2 in 2008
	Rate of daily wage at RLR harvest	150	baht/person	

baseline scenario. Incomes from rice sales of smallholdings I and II were not significantly different, but they lost off-farm income usually received from household III and IV. In contrast, without any labor constraint, the large farming households III and IV earned higher incomes from selling high quality paddy thanks to faster harvests despite high labor costs.

However, the participating farmers argued that, actually, small farms may not lose their off-farm income as much as showed by the simulated results because these immigrant workers are less likely to be hired because they are not considered as meticulous rice farmers. Furthermore, local farmers seem to prefer to hire laborers within their kinship networks.

No water constraint scenario

The simulated results showed that the synchronization of rice farming activities (here all farms are able to start producing rice at the same time) was unlikely to change the situations of larger farm III and IV compared to the baseline scenario. Farm III and IV could not hire extra workers at the beginning of transplanting like they did in the baseline scenario. However, transplanting can be prolonged without critical damage to rice productivity. Therefore, farmer III and IV could complete transplanting by hiring extra workers from household I and II once these households finished this activity on their small holdings. In this scenario, a small virtual farm II could not complete transplanting of its entire farm when the heavy rains came late, and by then some rice seedlings were too old to be used. Compared to the baseline scenario, it shows little difference in terms of local off-farm income gained by small farms and labor cost paid by large farms.

However all participants said that the impossibility to transplant paddy fields was unlikely to happen in reality because rice farmers take adaptive measures like establishing more nurseries or buying rice seedlings from their neighbors. Nevertheless, this simulated outcome helped the participants to reflect on such a risk-taking decision in relation to water dynamics that may cause them to spend more cash on additional rice seedlings.

DISCUSSION

KIDS or KISS? Or both!

As expressed by the familiar motto “Keep It Simple and Stupid” (KISS), simpler models are widely considered as more useful than complex ones [9]. In the field of social simulation, in contrast to the KISS motto that praises ambitious abstract, high-level modeling, Edmonds and Moss (2004) [11] have proposed a new slogan -“Keep It Descriptive, Stupid” (KIDS)- to claim that the systematic reference to the law of parsimony should not prevent for more low-level, descriptive modeling. This provocative slogan seems to call for a radical positioning of modelers among those who would rather place a colon or a comma between “keep it descriptive” and “stupid”.

However, we believe that both KISS and KIDS principles are worthwhile, especially when the aim of the modeling process is to foster co-learning among scientists and stakeholders. Before starting to directly interact with the local farmers, researchers engaged in the modeling process to synthesize the existing scientific knowledge. At this stage, any relevant information was integrated into the prototype model, according to the KIDS principle. For instance, an existing hydrological module that was previously developed to precisely simulate the availability of water in paddy fields and ponds in this Lam Dome Yai watershed[16] was integrated into the first version of the BMM model. During the collaborative modeling process, we realized that farmers were making decisions about rice-growing activities in relation to water availability by directly referring to daily rainfall conditions. Furthermore, we had difficulty to make transparent to participating farmers complicated hydrological processes such as infiltration, percolation, and diffusion. For these reasons, the sophisticated hydrological module was replaced by a simple parameter set to a constant value (10 mm) to account for daily water outflow from a paddy field in this RLR ecosystem.

Validation: a shared representation of the interactions between land & water use and labor migration

Validation relates to the extent to which the model adequately represents the system being modeled [6]. The canonic view of validation mainly considers the difference between simulated and observed data. The goodness of fit makes the model “right”. However, the correlation between observed and simulated data might be induced by irrelevant mechanisms introduced in the model [1].In any case, the validity of a model should not be thought of as binary event (i.e. a model cannot simply be classified as valid or invalid). The adequacy of the representation provided by the BMM model refers to its acceptance by the local farmers who participated to its collaborative design as a fair and useful representation of the interactions between land & water use and labor migration in their village. According to the ComMod principles, this representation was built through the confrontation of the views of different types of stakeholders and the views of the researchers in order to clearly express scenarios built to explore the opportunities and dangers of an uncertain future [20].

The BMM model has been recognized by the participating farmers to be sufficiently accurate to represent their current situation. As a result, they eventually proved to be comfortable and confident enough with it to present and comment the BMM model in front of master students and lecturers-researchers -who did not participate to the modeling process - at the Faculty of Agriculture, Ubon Rajathanee University, on October 18, 2008. The discussion that followed the demonstration showed that most of the students have different views and understandings and even concepts about RLR farming in northeast Thailand. This confirmed the fact that any model might be an accurate representation of some stakeholders' views, but at the same time, an inaccurate (though precise) one for other differing stakeholders' views [20]. Such collaborative modeling practice is valuable because of its efficiency in communicating and therefore sharing such diversity of viewpoints.

From singular representations of actual households to the abstract concept of a BMM household

The first ABM was introduced to the participating farmers in a workshop organized in April 2007. This ABM was initialized from the exact circumstances of the 11 households who participated in the process. During this workshop, we had difficulty to stimulate collective discussions to refine the model, and to get a collective agreement on the validation of this model. This was because all the participants attempted to correct the individual dissemblance that they found in the model compared to their actual situation.

To enhance such a collective discussion, we simplified the model to represent only 4 farms, with characteristics based on a previous farm survey and typology [23], as shown in the latest version of the BMM model described above. We organized 4 sub-workshops, with small groups of farmers belonging to the same farm type, to fine-tune this simplified model. Although this latest version is more abstract than the first one, it was accepted by all the participating farmers to sufficiently represent their system in the last workshop held in May 2008.

CONCLUSION

The BMM model is undoubtedly a site-specific model, far from a generic tool. The process of designing it was a long and costly one with only a local impact so far. This inescapably raises the question of the cost-benefit of the whole approach. In term of out-scaling, the current model can be considered as a communication tool to be reused in villages similar to BMM to stimulate knowledge sharing, leading to the enrichment of the underlying conceptual model. We believe that the computer model could be introduced straightforwardly to other farmers without being perceived as a "black box" if the presentation is made by the BMM farmers themselves: there is no reason why the communication of the model among farmers would be more problematic than the communication of the model from farmers to scientists.

Finally, from this experiment, we found that it is possible to use collaborative modeling with marginal rice farmers. We both researchers and participating farmers gained benefits through knowledge sharing by co-constructing the model.

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